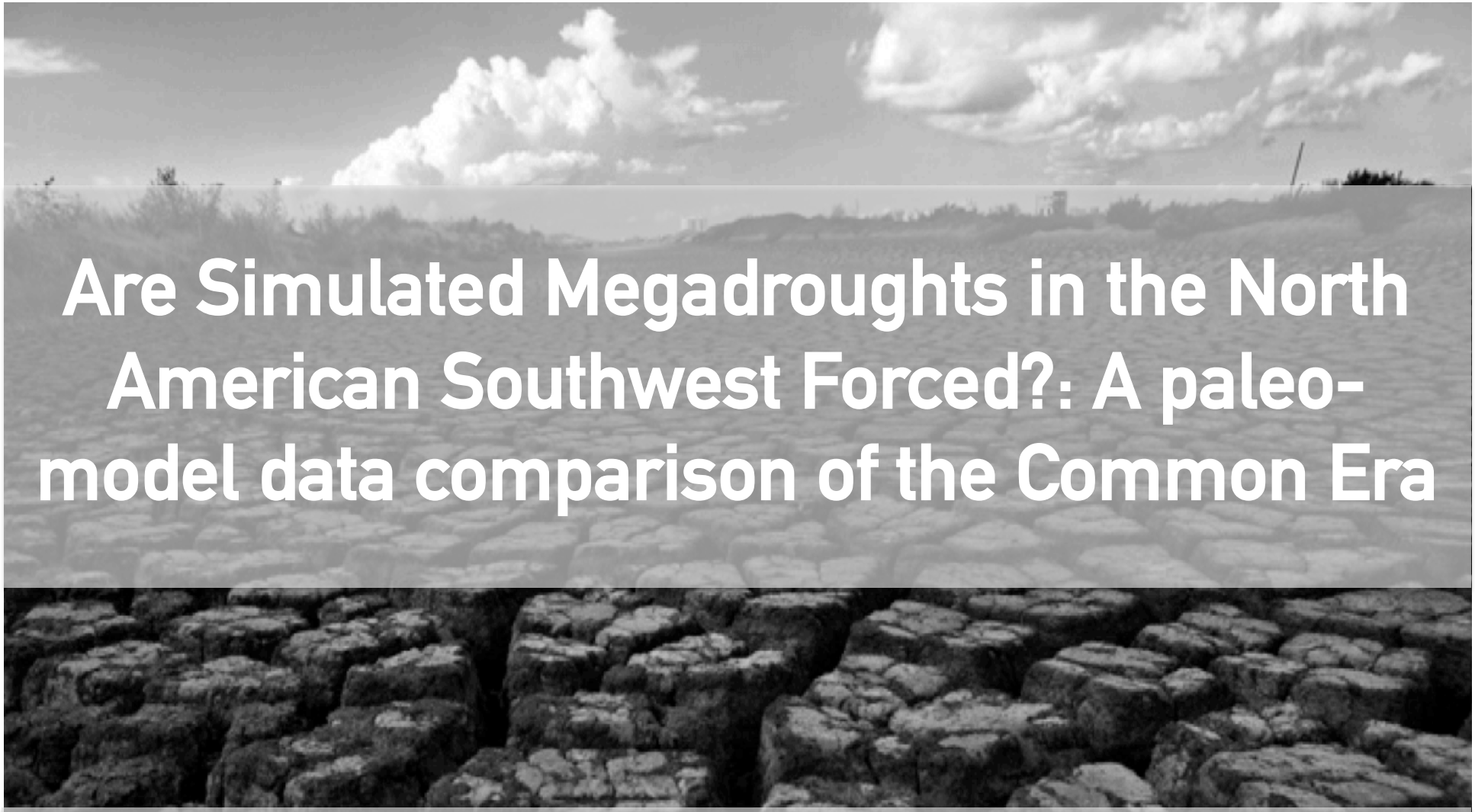
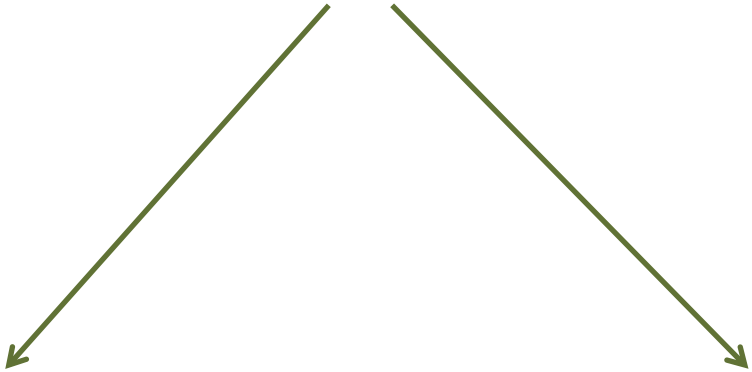


Are Simulated Megadroughts in the North American Southwest Forced?: A paleo-model data comparison of the Common Era

Sloan Coats, Jason E. Smerdon, Richard Seager,
Benjamin I. Cook, Haibo Liu, Naomi Henderson and
J.F. González Ruoco
Lamont Doherty Earth Observatory, Columbia University
GISS Seminar: Nov. 12, 2014

Forced?



Exogenous

-Trace Gasses

-Solar

-Volcanic

SST Boundary

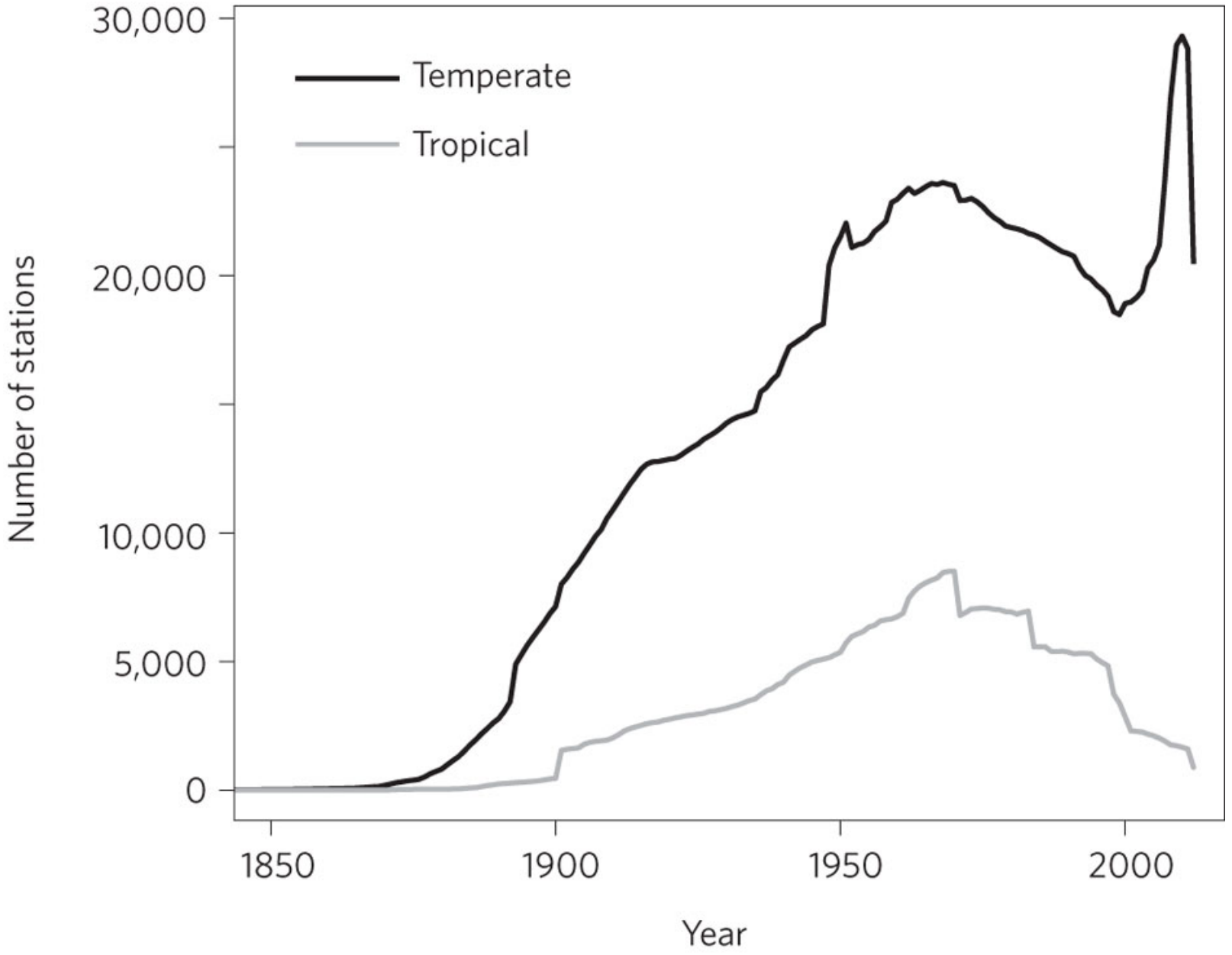
-ENSO

-PDO

-AMO

General Motivation

Why are paleo-model data comparisons of the Common Era (CE) important?



Paleoclimate record of the Common Era is best chance of extending the instrumental record with similar temporal and spatial resolution (with more uncertainty)

Forced-transient coupled model simulations are available for the Common Era (with forcing uncertainty)

Why decadal-to-centennial timescales?

Projecting Future Hydroclimate!

- How will hydroclimate respond to increasing greenhouse gas concentrations over the next decade to century?
- How will these forced changes combine with internal climate variability to determine the actual impacts of hydroclimate change?
- Are models able to capture the full range of internal and forced components of past hydroclimate change on decadal-to-centennial timescales?
- Subtle aside: Can models inform our understanding of decadal-to-centennial scale dynamics?

Specific Motivation

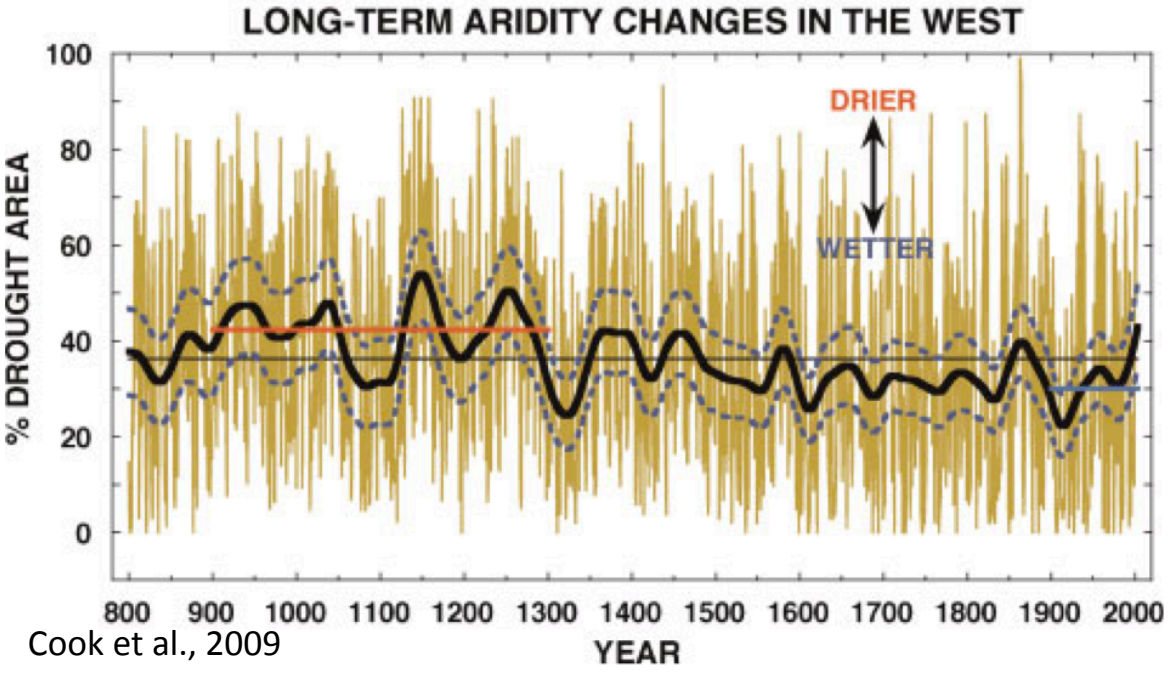
Why Southwestern North America?

16% of the U.S. population (U.S. Census Bureau, 2009)

Half of domestic food crop production (Parker, 2007)

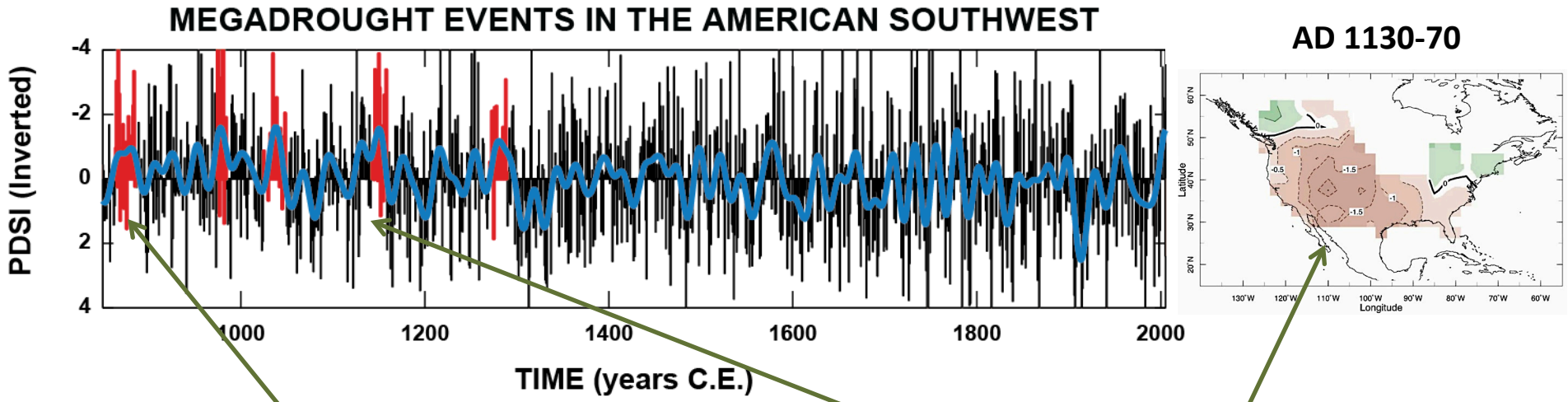
Water supply is fickle and unpredictable (Schlenker et al., 2007)

LM has decadal to century scale "megadroughts"



Cook et al., 2009

Megadrought Impacts



Temple of the Jaguar, Tikal

Pueblo Bonito, Chaco Canyon

Megadroughts are hydroclimate change on the timescale over which we hope to project future climate

To Start:
A Hypothesis

1) Models will simulate drought that is characteristic of the megadroughts in the paleoclimate record.

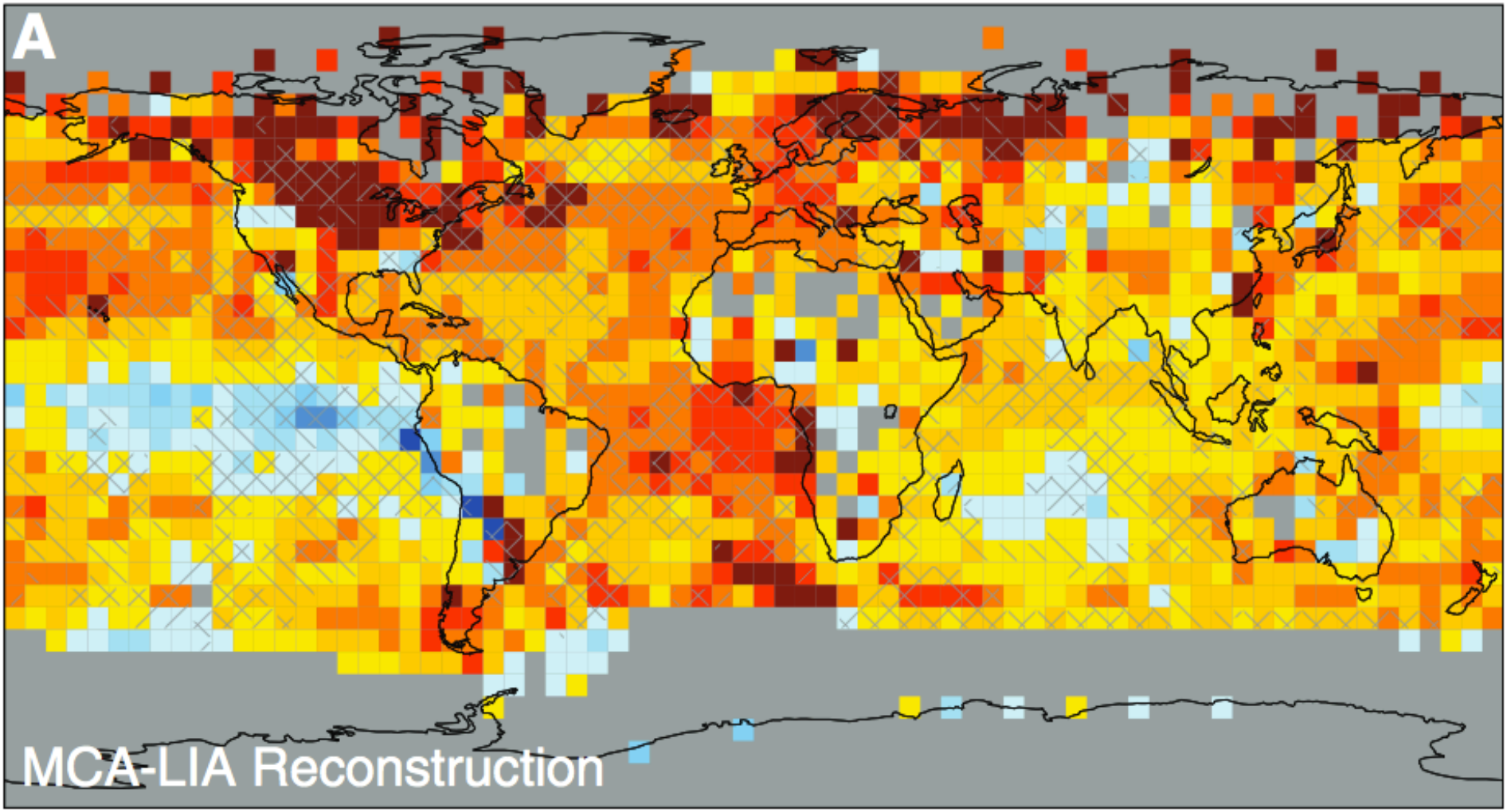
2) These features are exogenously forced and will be contemporaneous with those in the paleoclimate record.

3) The exogenous forcing will drive changes in the tropical Pacific boundary conditions via ocean dynamical mechanisms, which will produce megadroughts via atmospheric teleconnections.

Why point #3?

The tropical Pacific is the dominant driver of interannual variability in Southwestern hydroclimate

Tropical Pacific and past hydroclimate change?



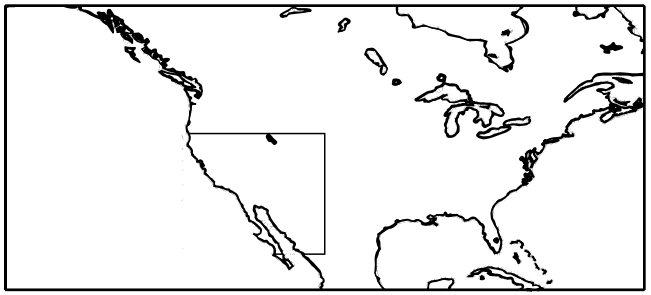
Mann et al. (2009) reconstruction showing cold tropical Pacific during MCA

Megadroughts and the ECHO-G Model

Coats, S., J.E. Smerdon, R. Seager, B.I. Cook and J.F. González-Ruoco, Megadroughts in Southwestern North America in Millennium-Length ECHO-G Simulations and their Comparison to Proxy Drought Reconstructions, Journal of Climate, 2013

Methods: Creating a hydroclimate index

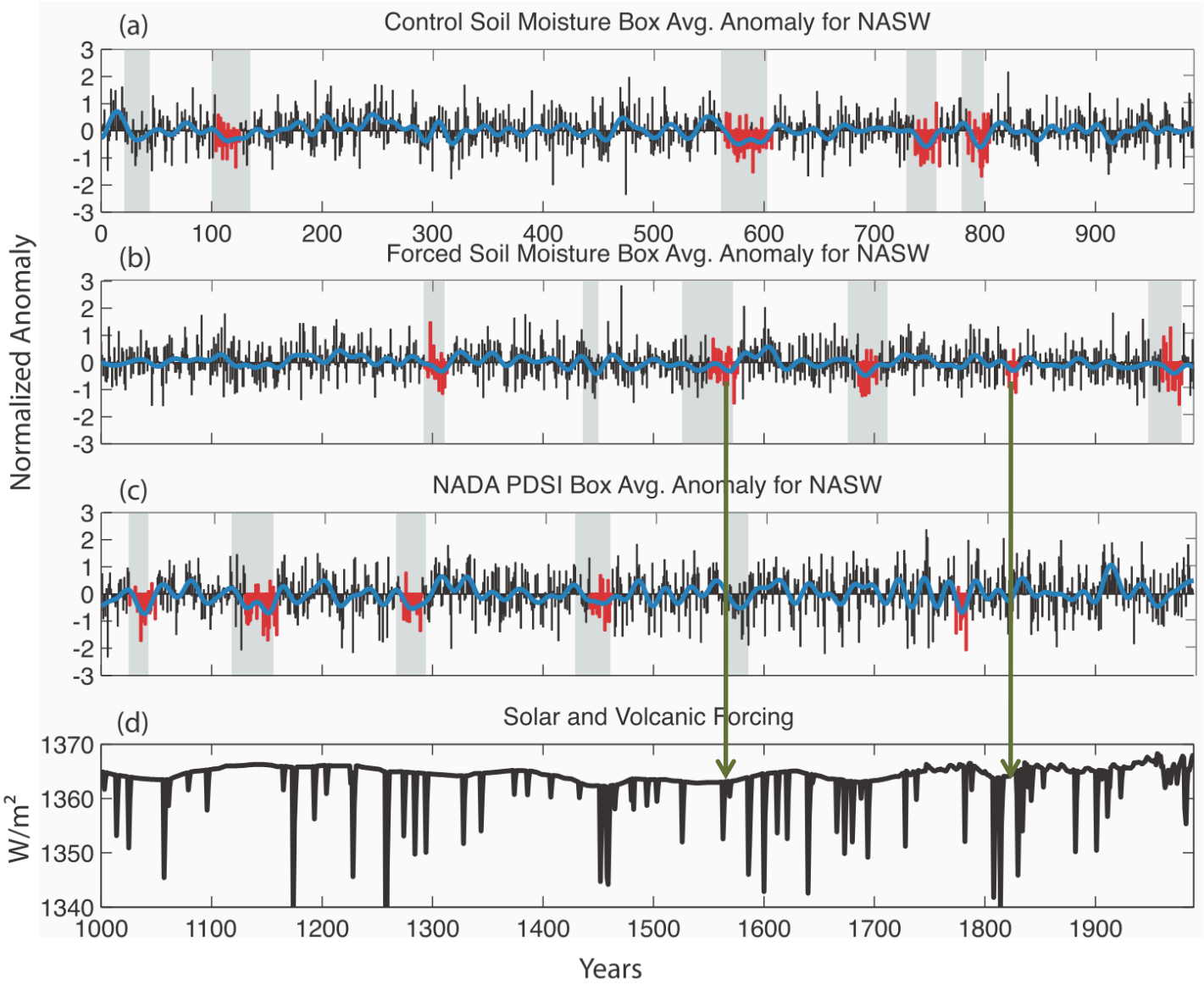
- **JJA PDSI from the NADA is ground truth**
  - Palmer Drought Severity Index is an offline model of soil moisture balance, calculated from inputs via precipitation and losses due to evapotranspiration.
- **Annual soil moisture is the input from ECHO-G:**
  - 2.5° x 2.5° lat-lon grid
  - Both forced and control simulations are utilized
- **Hydroclimate timeseries was created by averaging the PDSI and soil moisture over the Southwest (125°W-105°W, 25°N-42.5°N)**



Methods: Identifying drought

- Droughts identified using the 2 start 2 end method
- Droughts ranked using drought density method
- Top five are chosen for analysis of dynamics that drive persistent drought
- Results not dependent on “arbitrary” metric (Coats et al., 2013a)

Can ECHO-G Simulate Megadroughts?



Internal Var.

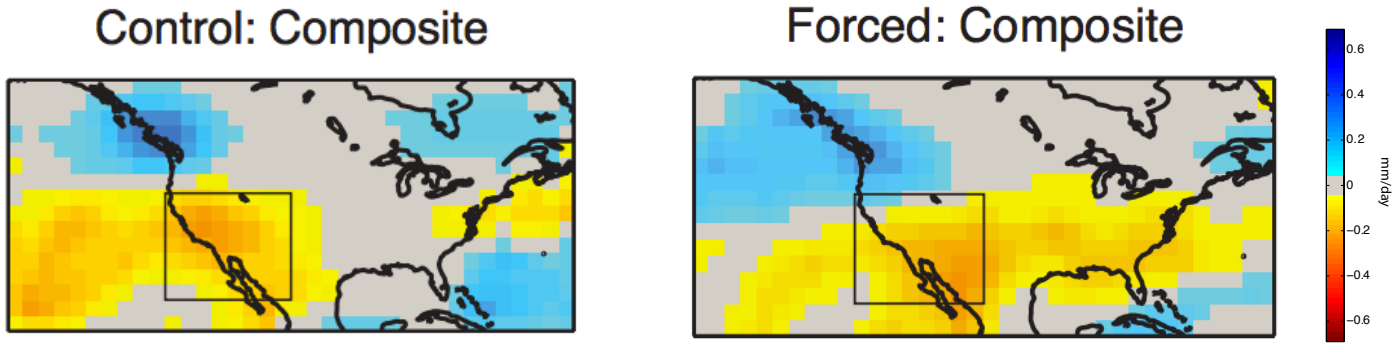
Forced + Internal Var.

"Observed" Var.

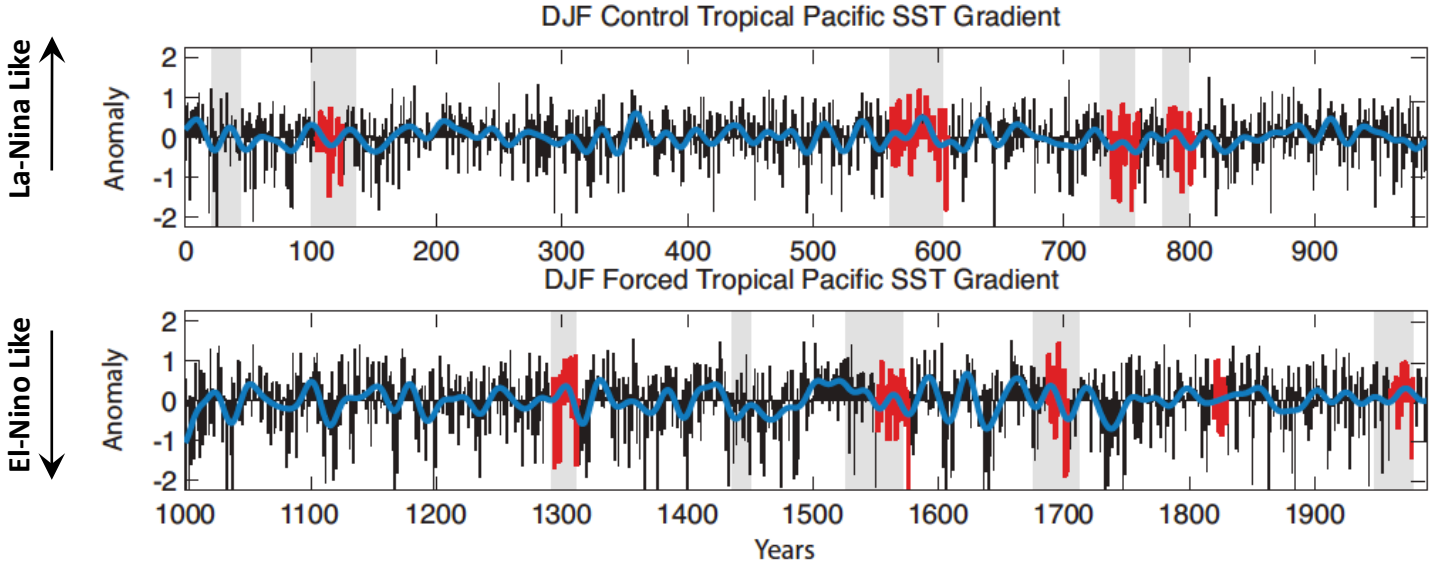
ECHO-G simulates megadroughts without a preferred forcing state

What is driving the megadroughts?

Composite Winter Precipitation Anomaly for Megadrought Years



Tropical Pacific SST Gradient: Megadrought Timing in Red



Megadroughts in the ECHO-G model can be driven by stochastic atmospheric variability

Hypothesis: After ECHO-G Analysis

1) megadroughts

✓

2) exogenously forced

✗

3) tropical Pacific

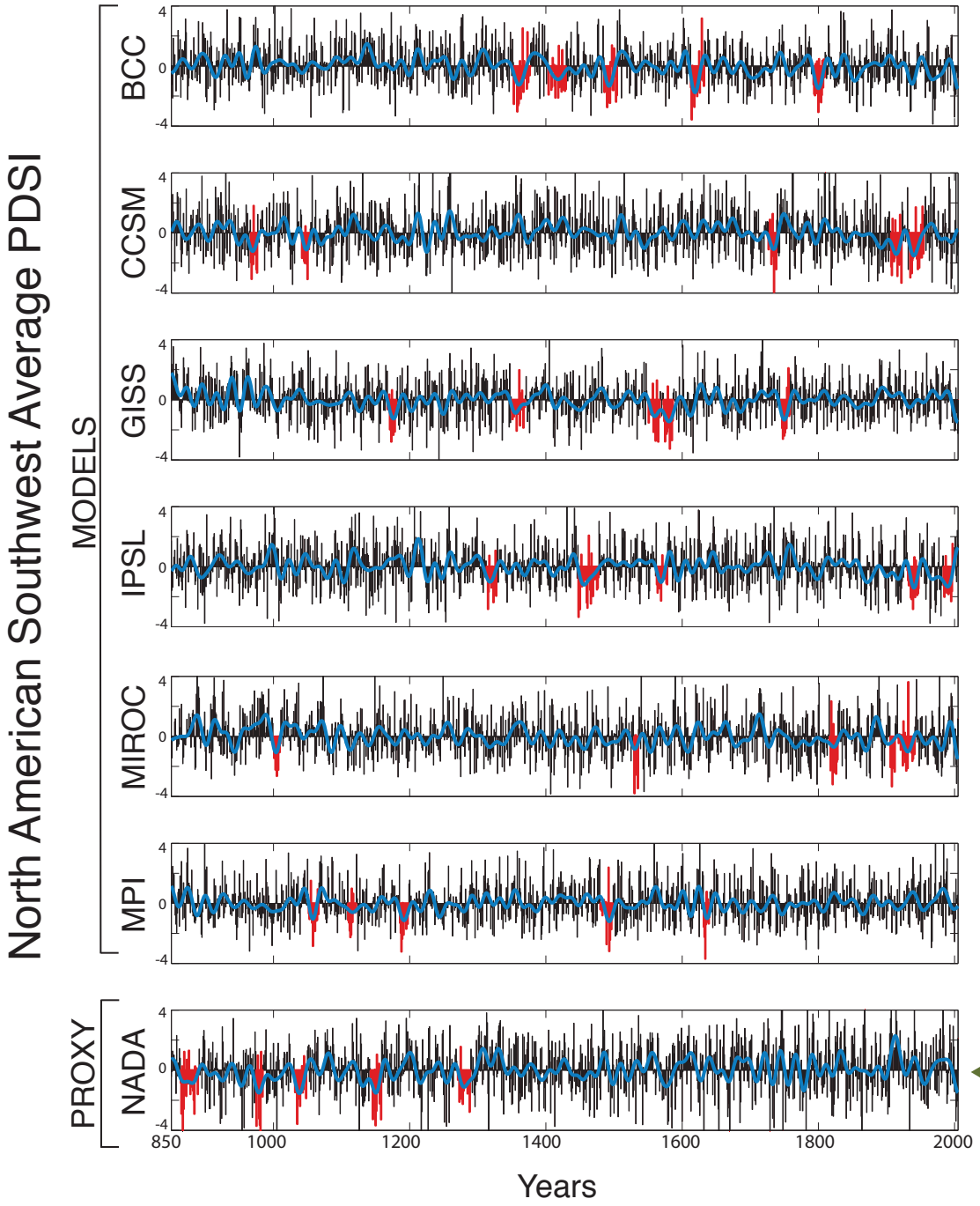
✗

Is this a robust model characteristic and why should we care?

Megadroughts in a Multi-Model Context

Coats, S., J.E. Smerdon, B.I. Cook and R. Seager, Stationarity of the Tropical Pacific Teleconnection to North America in the CMIP5/PMIP3 Model Simulations, Geophysical Research Letters, 2013

Coats, S., J.E. Smerdon, B.I. Cook and R. Seager, Are Simulated Megadroughts in the North American Southwest Forced?, Journal of Climate, In Review



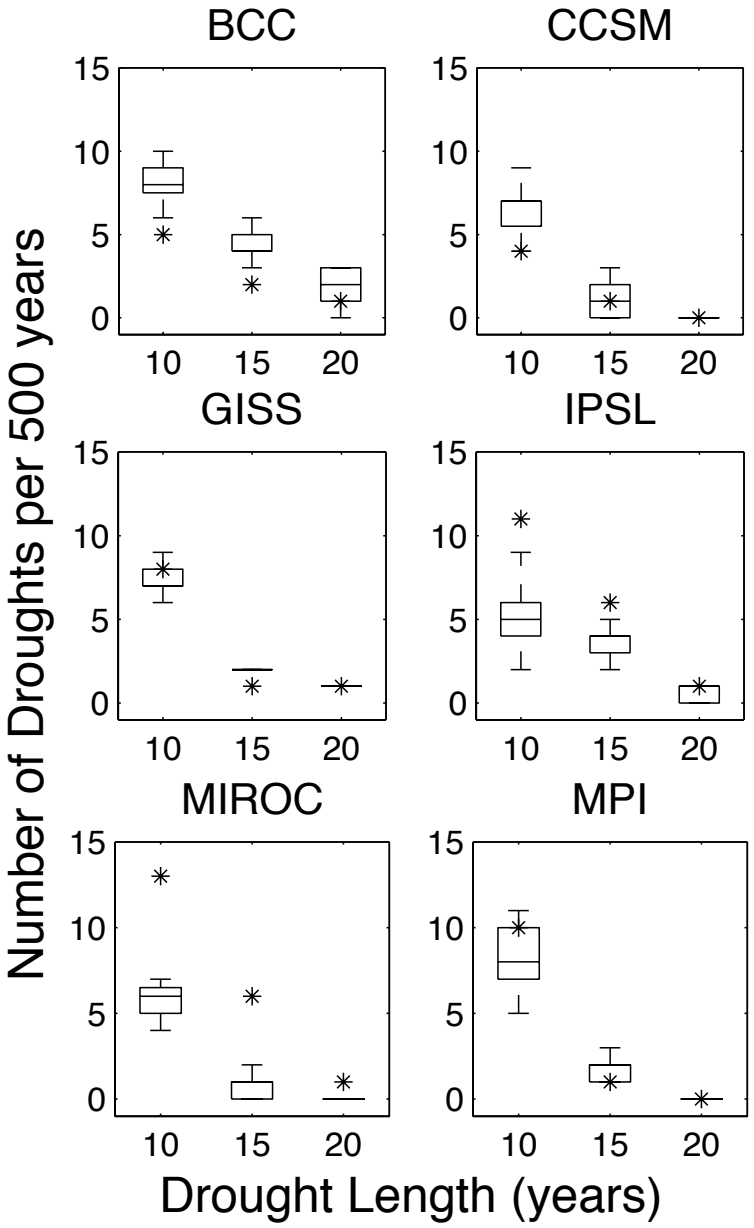
Do all models simulate megadroughts?

Models simulate drought that is characteristic of proxy estimated megadroughts

No agreement in drought timing across models

Paleoclimate estimated drought variability

Forced vs. Control

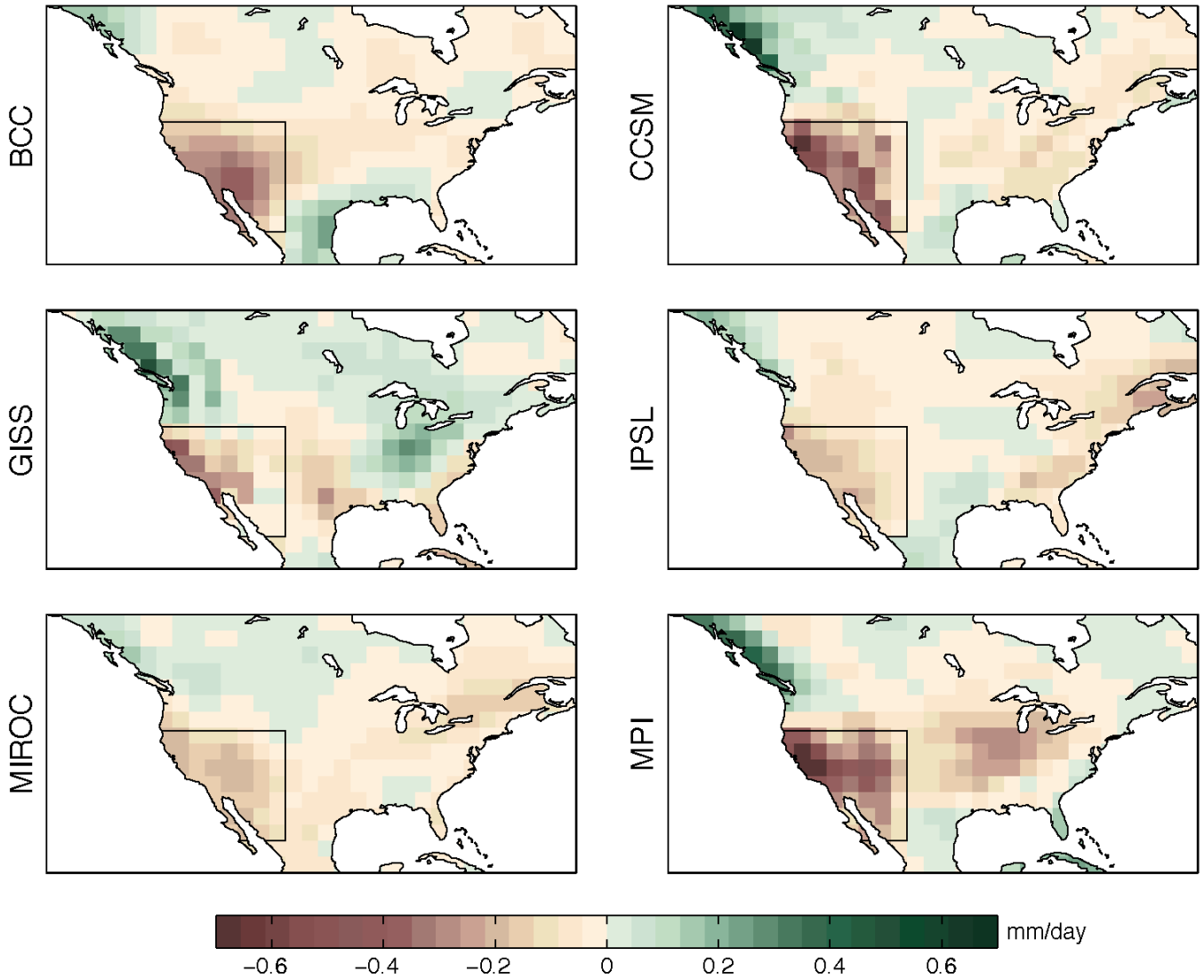


Hereinafter dynamics will be analyzed in control simulations with constant pre-industrial forcing conditions (unless noted)

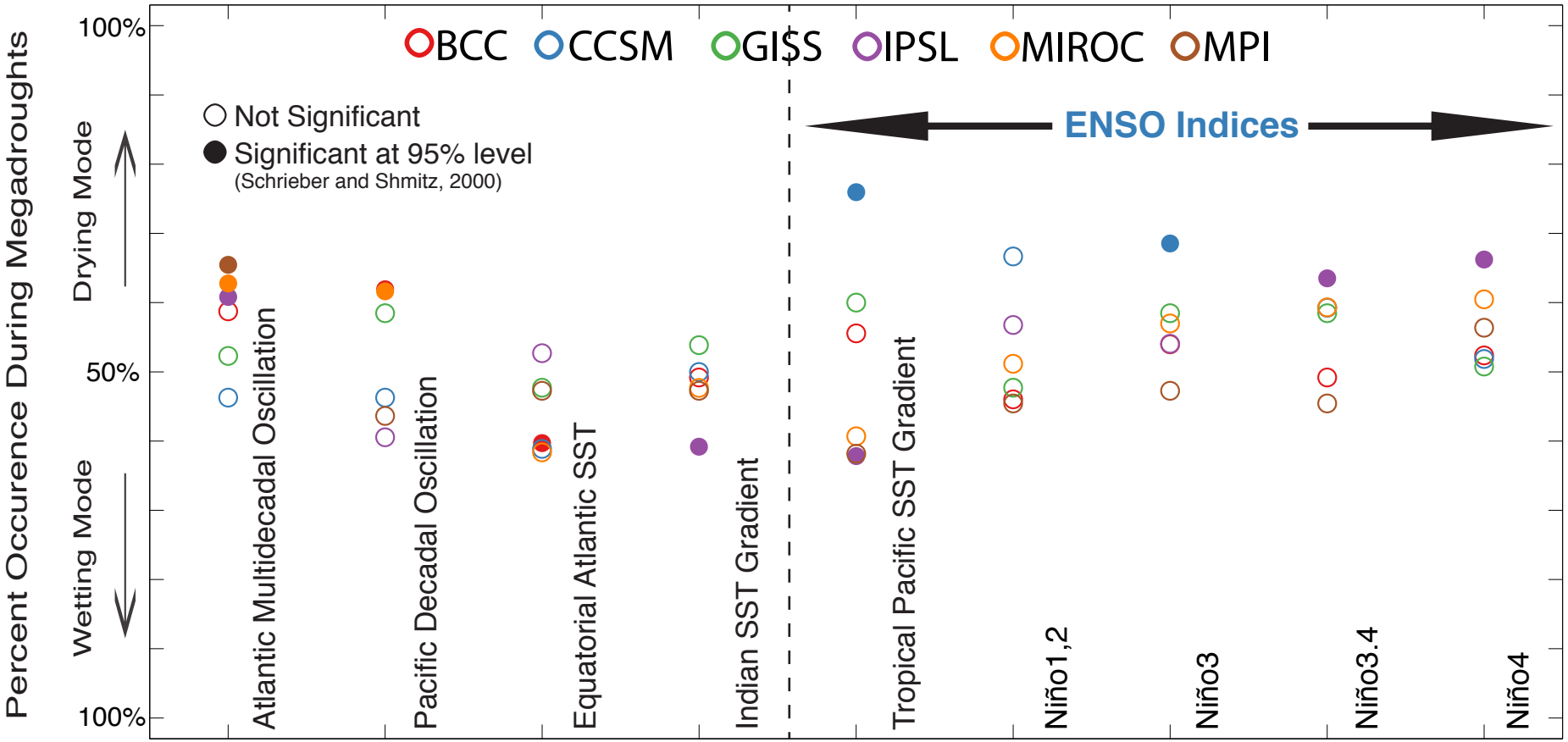
Winter/Summer? Precip/Evap?

Megadroughts result from anomalously low winter (DJF) precipitation over the SW

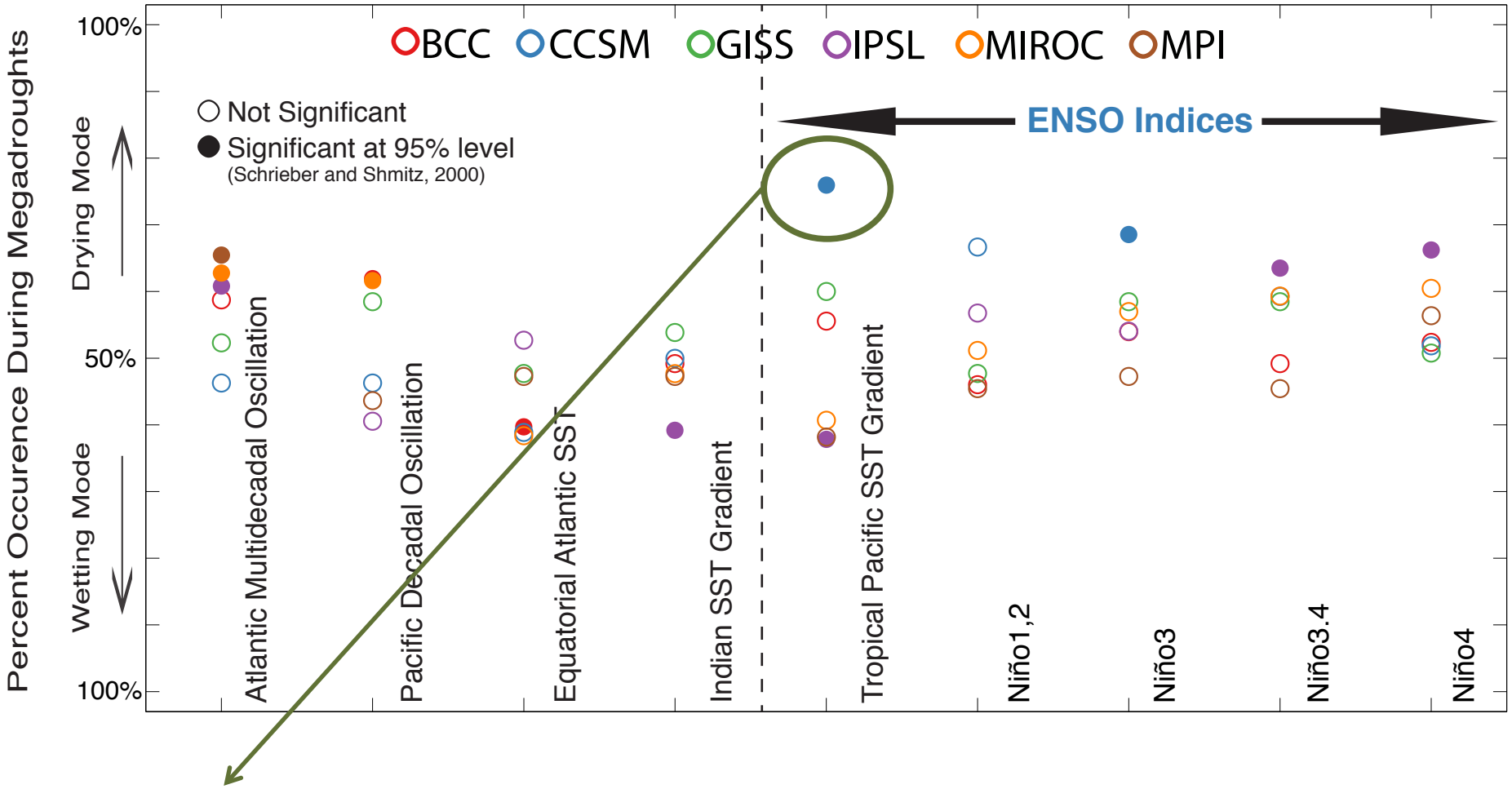
Pattern is characteristic of that driven by the La Niña



Multi-Model Dynamical Diagnostics



Multi-Model Dynamical Diagnostics



CCSM is exceptional in simulating megadroughts consistently forced by the tropical Pacific

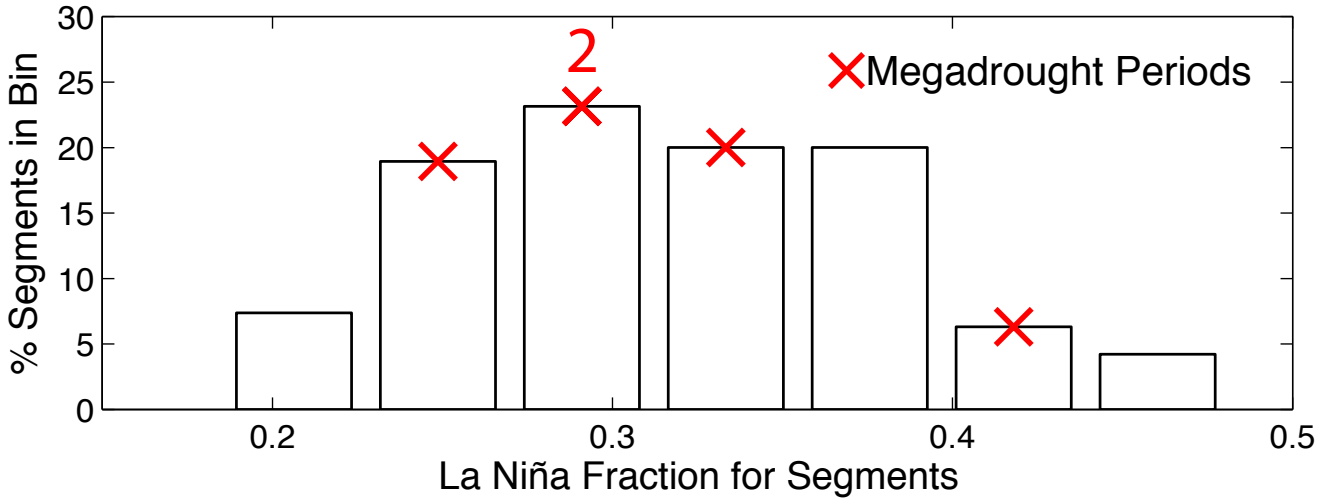
Analysis of CCSM

1) What is happening in the tropical Pacific during the identified megadrought periods?

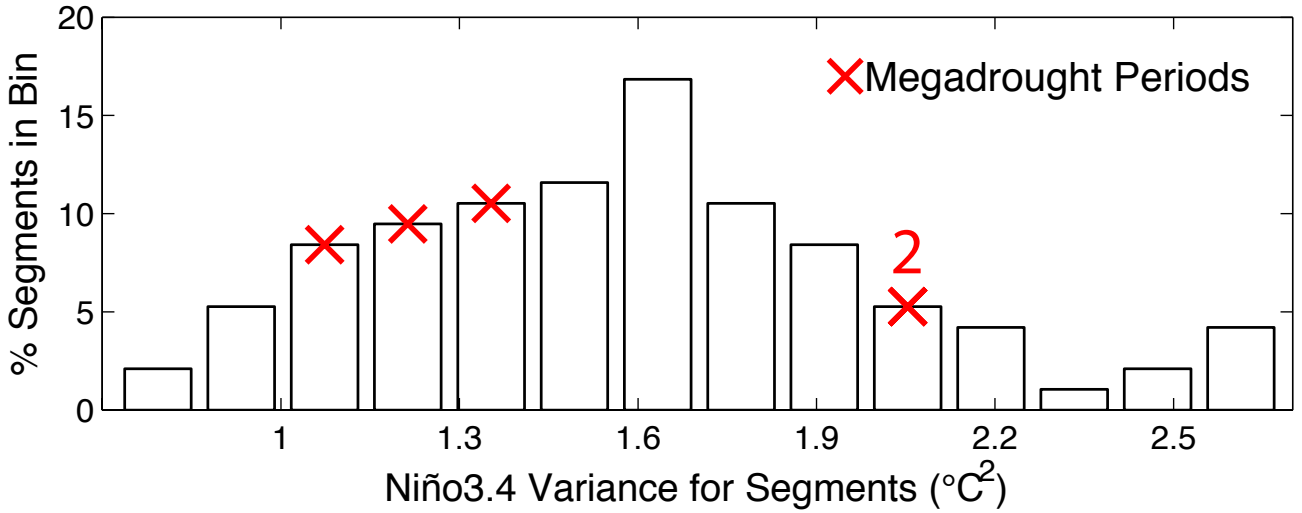
2) Why does the CCSM model exhibit an exceptional connection between megadroughts and the tropical Pacific ?

Mean-state change or a change in tropical Pacific variability?

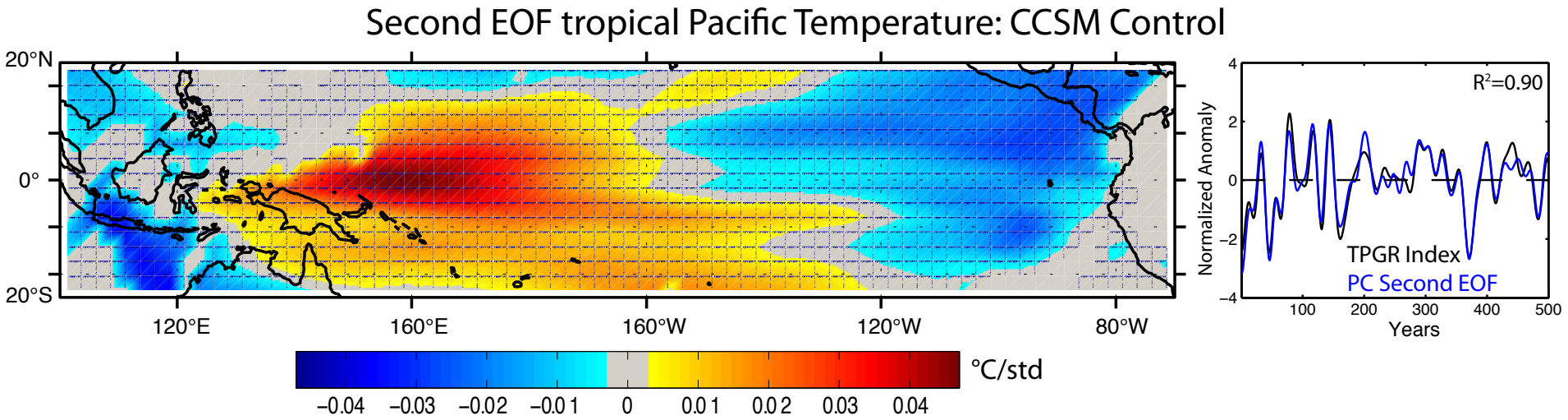
Megadrought periods in CCSM have approximately average Niño3.4 statistics



TPGR consistent with a shift toward a more La Niña-like mean state



Is the change in mean state forced?



Probably Not: TPGR on multidecadal timescales in CCSM is driven by the internal Centennial Pacific Oscillation (Karnauskas et al., 2012) mode of variability

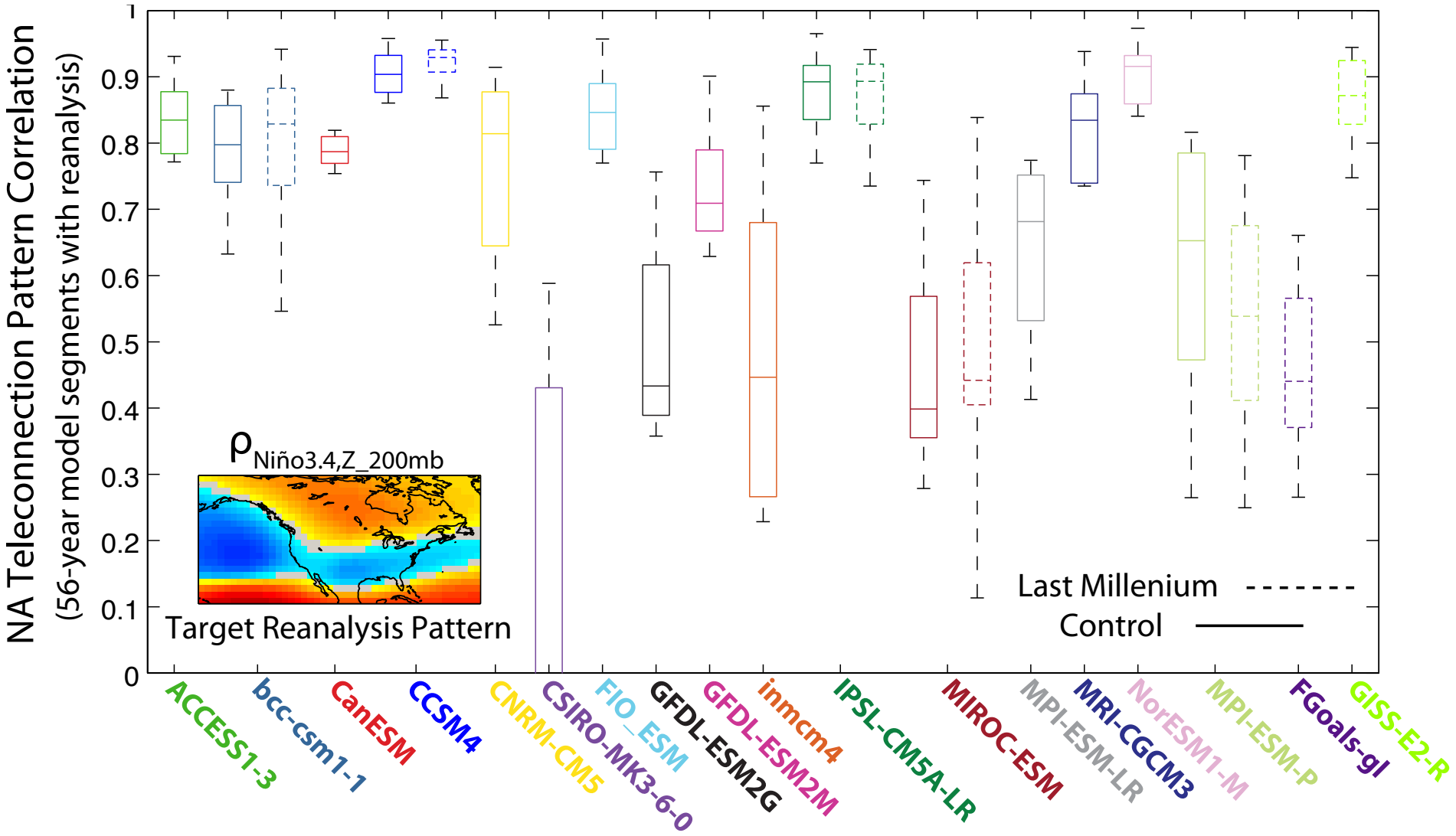
(Though forcing can project onto internal modes of variability)

What is different about CCSM? A hypothesis

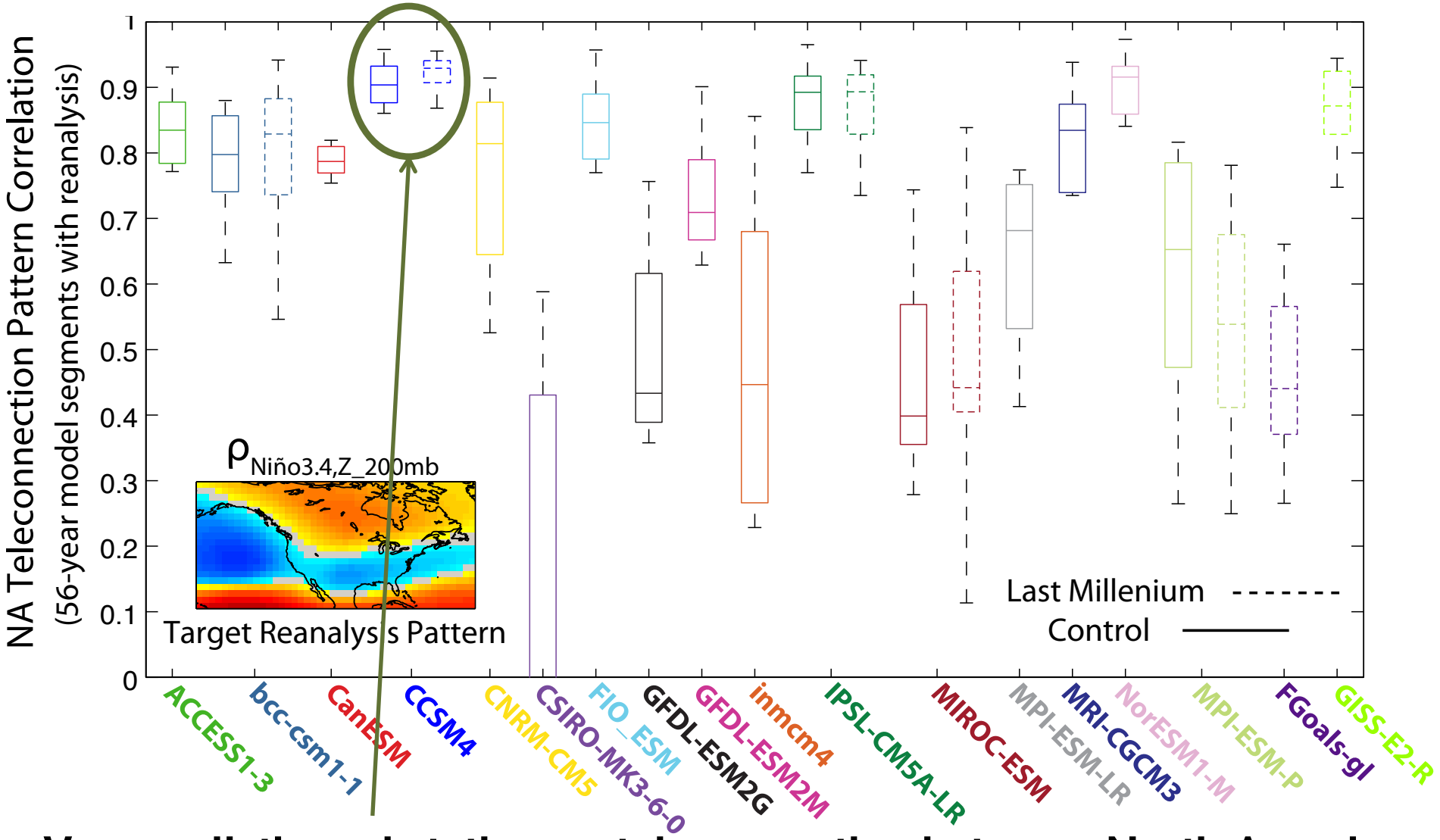
Stochastic atmospheric variability (and internal modes of coupled atmosphere ocean variability outside of the tropical Pacific)…can produce storm track shifts that are uninterrupted by tropical Pacific influence because of the weak (and non-stationary) ENSO teleconnection on multidecadal timescales… *from Coats et al., 2013a*

Does this story hold for the CMIP5 models?

Teleconnection Strength and Stationarity

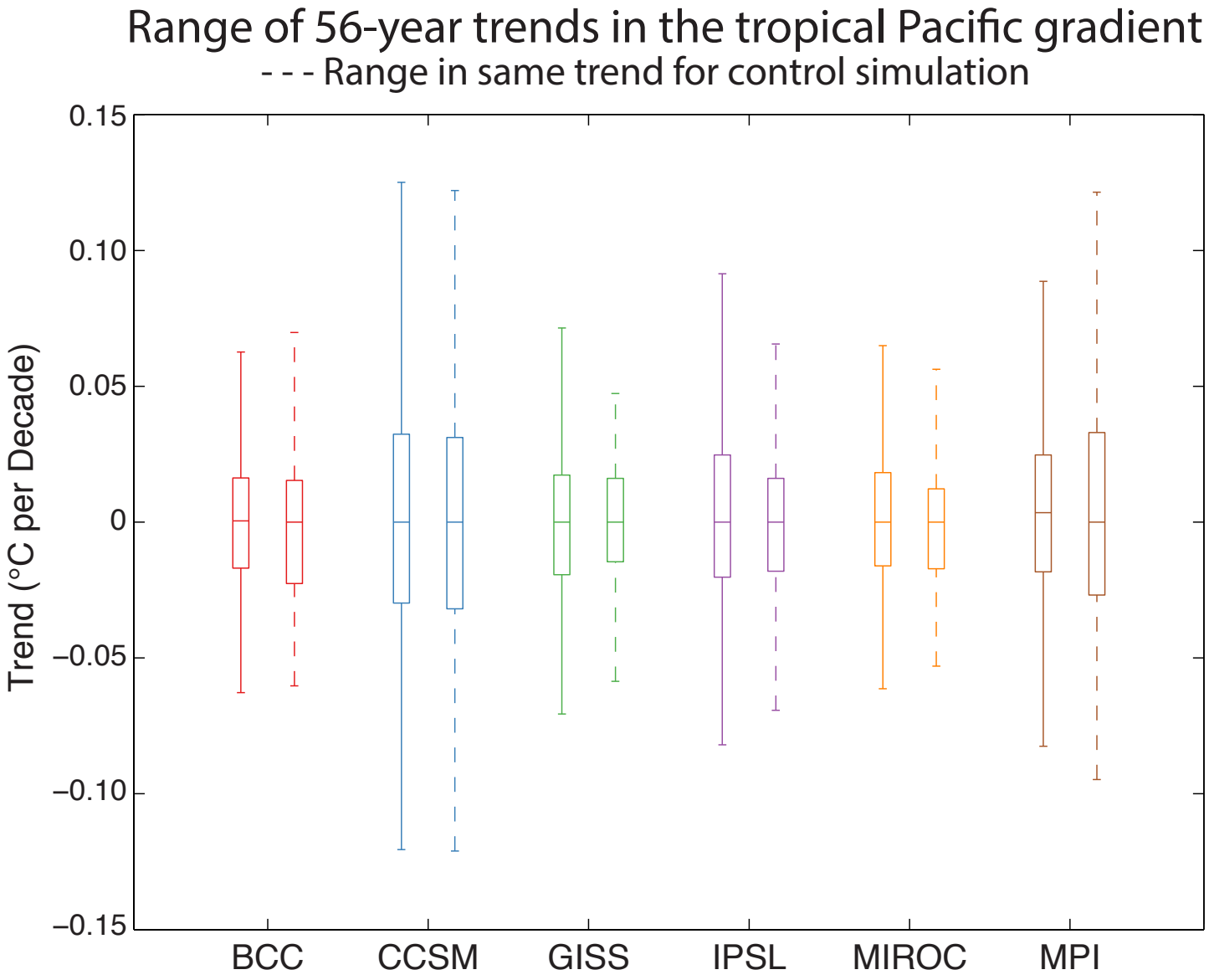


Teleconnection Strength and Stationarity

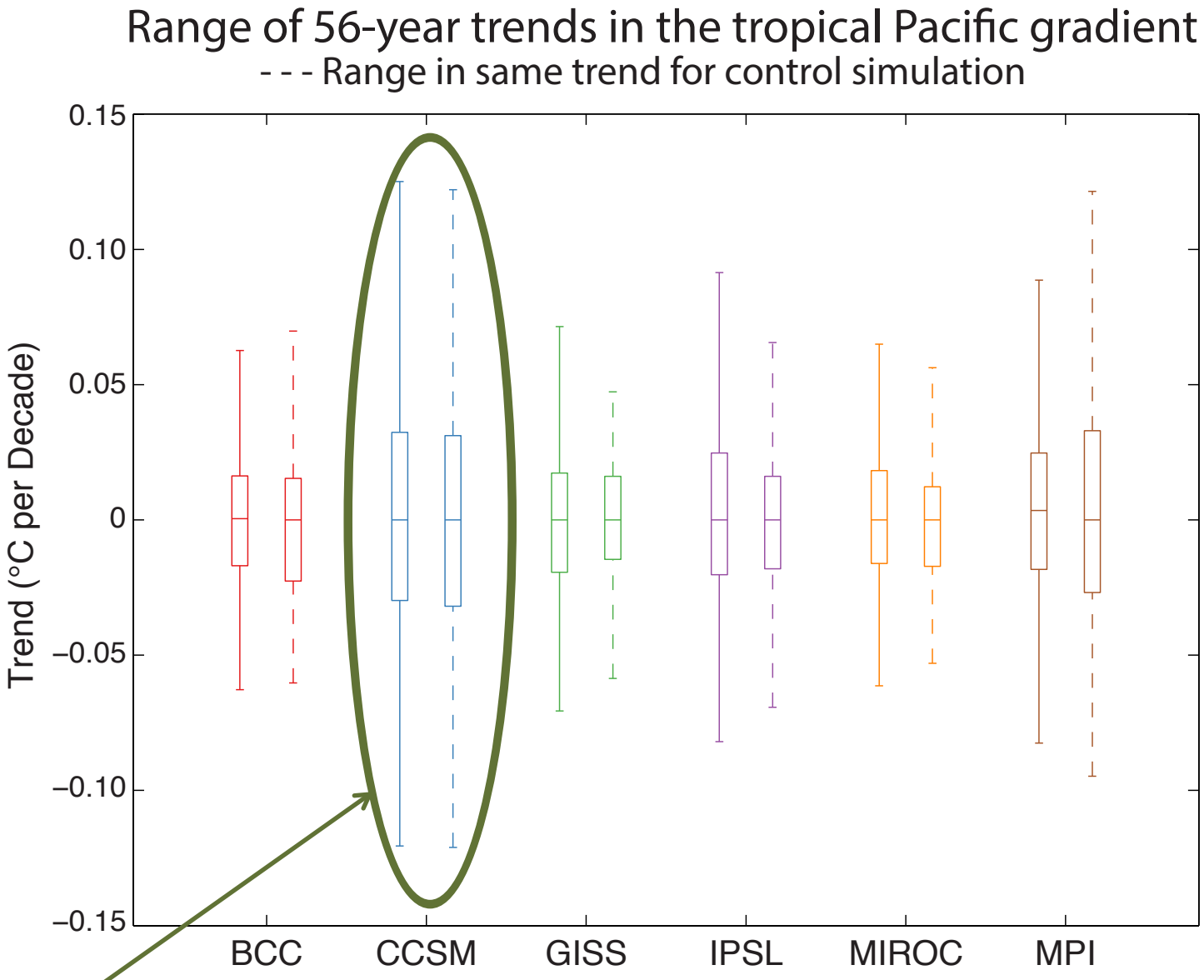


Very realistic and stationary teleconnection between North America and tropical Pacific for CCSM!

Multi-decadal Variability in the tropical Pacific

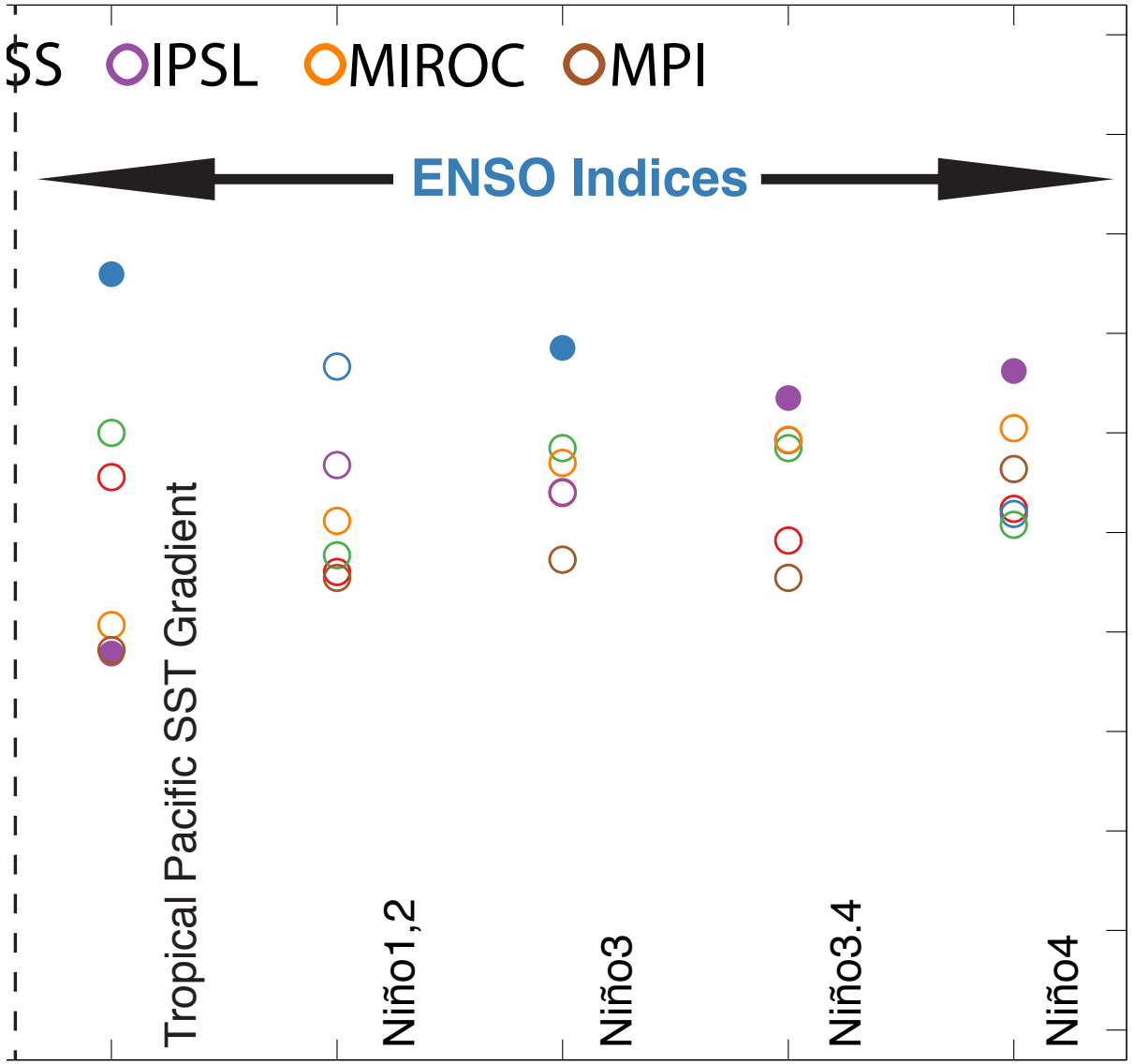


Multi-decadal Variability in the tropical Pacific

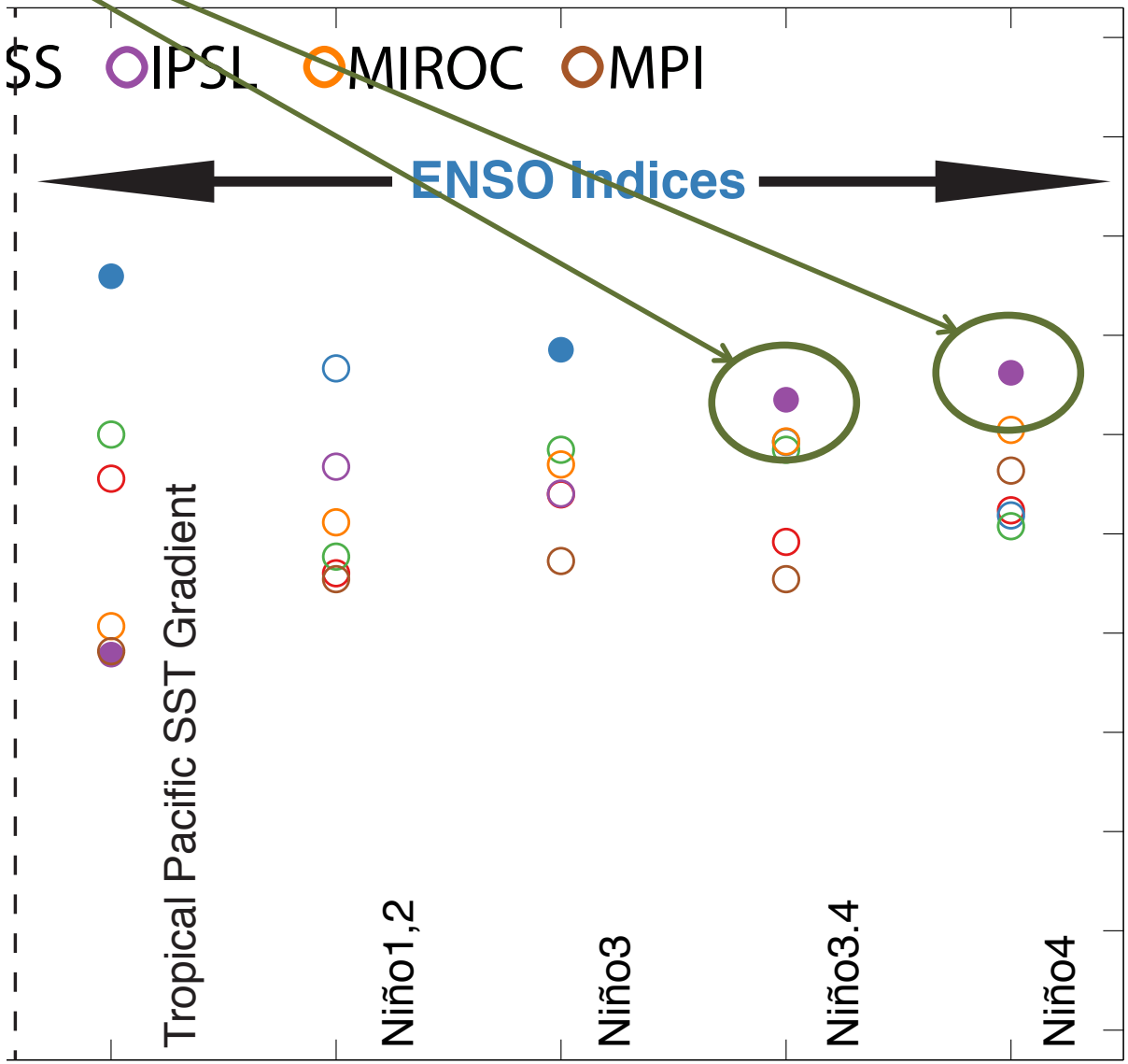


Largest multi-decadal variability in the TPGR

IPSL has a weaker but still significant megadrought connection to tropical Pacific

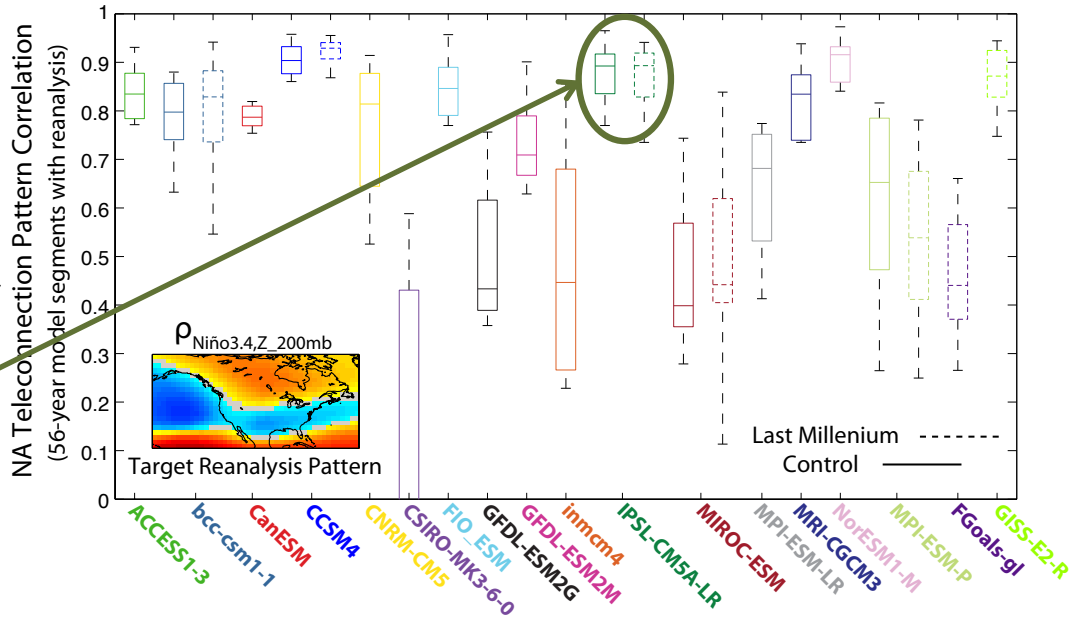


IPSL has a weaker but still significant megadrought connection to tropical Pacific

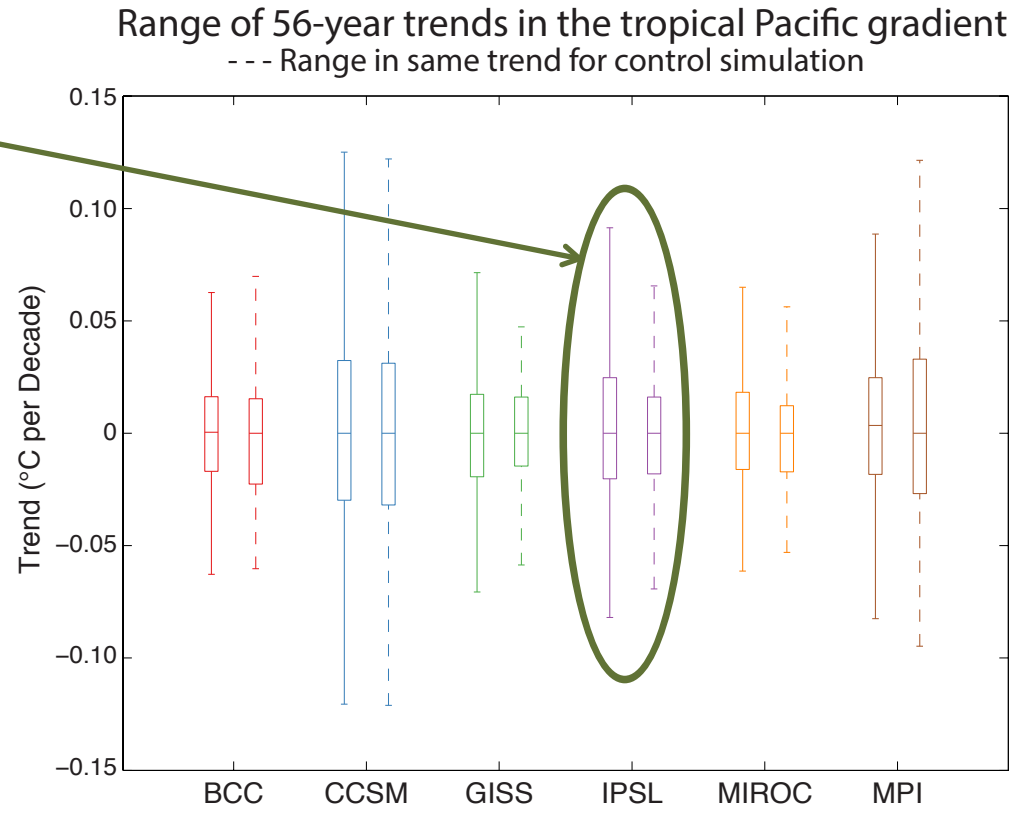


ISPL

-Realistic and stationary teleconnection



-Moderate variability in the tropical Pacific



-Most CCSM-like of the other models

Other Models

- **IPSL exhibit a weaker but still significant connection between megadroughts and the tropical Pacific**
- **BCC, GISS, MPI and MIROC have no significant connection between the tropical Pacific and megadroughts:**
  - MIROC and BCC have weak multi-decadal variability in the tropical Pacific and a highly non-stationary teleconnection
  - GISS has a stable teleconnection but weak multi-decadal variability in the tropical Pacific
  - MPI has a highly non-stationary teleconnection but large multi-decadal variability in the tropical Pacific

Hypothesis: After Multi-Model

1) megadroughts

✓

2) exogenously forced

✗

3) tropical Pacific

✓✗

Paleo/Model Data Comparison

- **Where and how else might these be useful?**
  - Any climate feature that:
    1) Has long timescales of variability
    2) Is rare
    3) Is potentially non-stationary

Instrumental interval provides too few degrees of freedom

1) Megadroughts: Coats et al., *J. Clim.*, 2013; Coats et al., *J. Clim.*, In Review(A)
2) Pan-Continental Droughts: Coats et al., *J. Clim.*, In Review(B)
3) Winter-to-Summer Prec. Phasing: Coats et al., in prep
   Teleconnection Stationarity: Coats et al., *GRL*, 2013